



Danish approach to handling of hospital wastewater

- from a pollution problem to new water resources



Who am I?

- M.Sc., Environmental Planning, University of Roskilde, Denmark, 2004
- Head of Projects
- DHI A/S, WasteWater Treatment
- 18 years of experience with EHS in wastewater – mainly pharmaceuticals and hospital wastewater



Aquaculture and agriculture



Energy



Climate change



Coast and marine



Surface and ground water



Urban water



Industry



Environment and ecosystems



Product safety and environmental risk



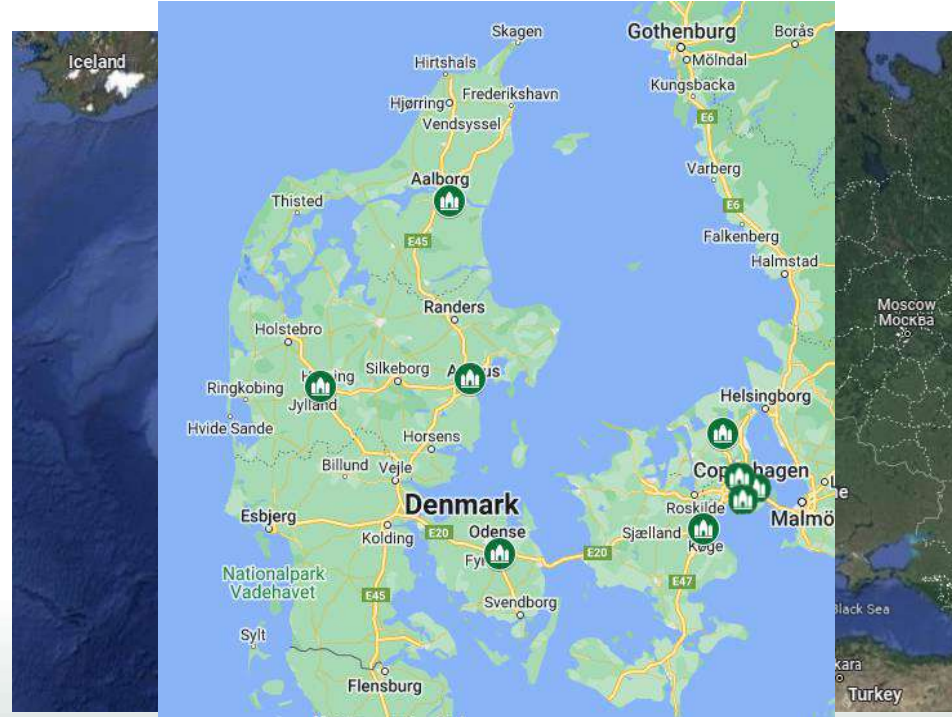
Agenda

- **Where are we?**
- **Pharmaceuticals – an environmental problem?**
- **Treatment of hospital wastewater at Herlev Hospital**
- **What is the situation today?**



Where are we?

- 5,8 mio inhabitants
- Capital: Copenhagen (0,5 mio.)
- 90-95% of all wastewater is treated
- 92% of treated wastewater is treated on advanced public WWTP's
- Public health care system
- 65 public hospitals
- 9 hospitals >500 beds





Pharmaceuticals from WWTPs

10 DK WWTP
48 sampling
campaigns

Pharmaceutical	No. of Measurements	No. of WWTP (average Conc. outlet > PNEC)	Conc. [ng/l]	Detection limit [ng/l]	No. Measurements (Conc > PNEC)	No. measurements (Conc < detection limit > PNEC)	PNEC [ng/l]
10,11-Dihydro-10,11-dihydroxycarbamazepin	14	4	240-1.700	N/A	14	0	100
17α-Ethinylestradiol	14	4	0,02-4,5	0,02 - 0,4	11	8	0,075
17β-Estradiol	14	4	0,013 - 950	0,05 - 2	11	10	0,1
Atorvastatin	21	8	9 - 1200	9 - 10	8	0	200
Azithromycin	48	10	10 - 930	≥ 10	43	0	19
Cefalexin	21	8	10 - 200	10 - 200	14	14	50
Ceftazidim	19	6	10 - 9.000	10 - 9000	14	13	130
Cyproteron	14	4	20 - 10.000	20 - 10.000	9	9	300
Diclofenac	48	10	10 - 862	N/A	48	0	50
Fulvestrant	14	4	20 - 500	20 - 500	14	14	0,57
Imidacloprid	32	4	10 - 2805	10 - 20	32	13	8,3
Roxithromycin	21	8	10 - 830	10 - 50	16	2	47
Sertralin	32	6	3,5 - 48	10 - 30	32	13	0,52
Sulfasalazin	14	4	10 - 51	10 - 50	14	10	10
Venlafaxin	48	10	14 - 770	N/A	45	0	100

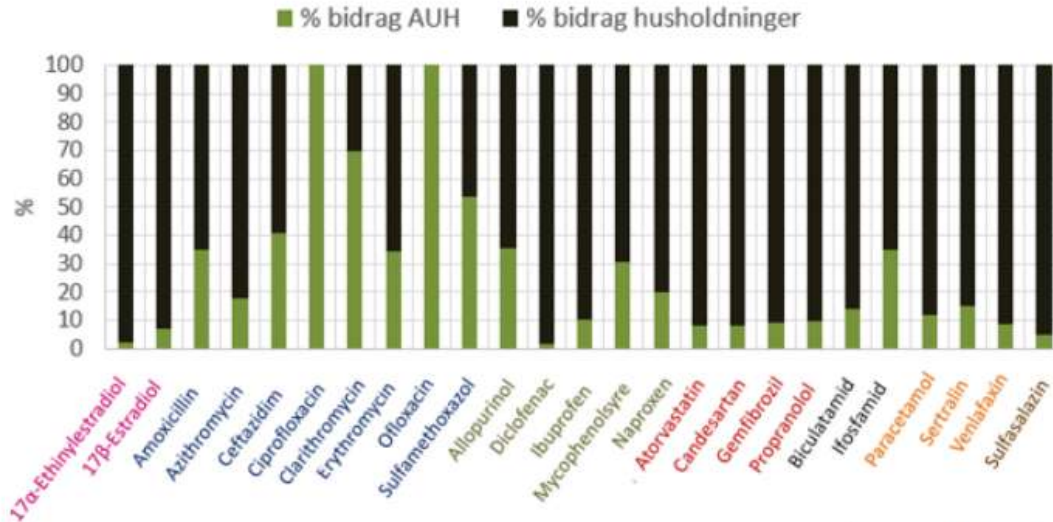
Report: [Medicinrester i spildevand og recipient \(danva.dk\)](https://www.medicinrester.dk)



Hospitals – a point source?

Green = University Hospital Aarhus with 862 beds

Black = Households





Hospitals – a point source?

- **Pharmaceuticals**

- Antibiotics
- Cytostatics
- Pain medicine
- Contrast media



- **Chemicals**

- Disinfection agents
- Laboratory chemicals



- **Pathogens**

- (Antibiotic resistant) bacteria
- Viruses
- Protozoa



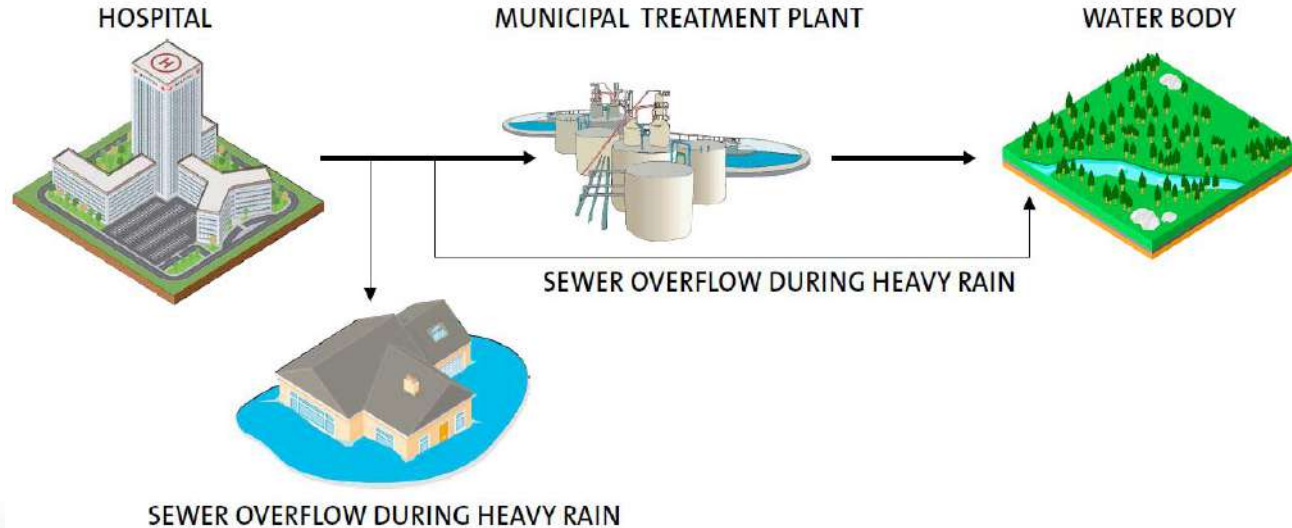
- **Radioactivity**

- E.g. I-131





Hospitals – a point source?





Regulation of Hospital WW

- Hospitals are regulated as industries in DK
- Wastewater permits are issued by the municipalities
- Guiding limit values for 40 hazardous pharmaceuticals (API's)
- According to Danish law hospitals must comply with BAT on wastewater treatment
- But what is BAT for treatment of hospital wastewater?

Table 3. Active/inactive concentrations for 40 hazardous pharmaceuticals and antibiotics at 0 - 3. Total antibiotic of EU

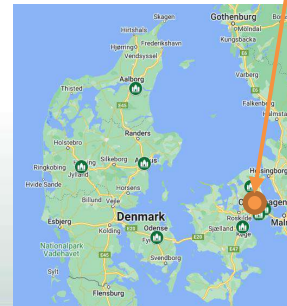
Substance	API Code	ATC Code	Source (D.I./A.I./M.I.C)	Reference	Freeware (mg/l)	Stability (year)	Retention assessment (%)	MHA (mg/l)	MHA (µg/l)	MHA (ng/l)
Amoxicillin	AN2001	A	Fish (Danish MDC: 0.01 mg/l)	(2)	3.4	5.7	17	0.7	0.57	0.17
Azithromycin	AN2002	A	Algal (Danish MDC: 0.1 mg/l)	(2)	1	2	9	1.0	1.0	1.0
Aztreonam	AN2003	A	Swedish (Danish MDC: 0.004 mg/l)	(4)	0.05	1.7	11	0.12	0.12	0.12
Benzimidazole	AN2004	B	Fish (Danish MDC: 0.1 mg/l)	(2)	0.1	3	3	0.1	0.1	0.1
Cloxacillin	AN2005	A	Fish (Danish MDC: 0.10 mg/l)	(2)	14	1	14	14	14	14
Cefazolin	AN2006	A	Algal (Danish MDC: 0.10 mg/l)	(2)	0.12	3	16	0.12	0.12	0.12
Cefepime	AN2007	A	Algal (Danish MDC: 0.10 mg/l)	(2)	0.12	1	41	0.14	0.14	0.14
Ceftriaxone	AN2008	B	Swedish (Danish MDC: 0.1 mg/l)	(4)	0.9	1.7	17	0.9	0.9	0.9
Cefuroxime	AN2009	B	Algal (Danish MDC: 0.10 mg/l)	(2)	0.12	3	16	0.12	0.12	0.12
Clarithromycin	AN2010	B	Swedish (Danish MDC: 0.1 mg/l)	(4)	0.12	3	16	0.12	0.12	0.12
Clavulanic acid	AN2011	B	Swedish (Danish MDC: 0.1 mg/l)	(4)	0.12	3	16	0.12	0.12	0.12
Doxycycline	AN2012	A	Swedish (Danish MDC: 0.10 mg/l)	(4)	1.4	3.7	17	0.9	0.9	0.9
Erythromycin	AN2013	B	Swedish (Danish MDC: 0.10 mg/l)	(4)	0.12	3	16	0.12	0.12	0.12
Fluconazole	AN2014	A	Algal (Danish MDC: 0.10 mg/l)	(2)	0.12	3	16	0.12	0.12	0.12
Gentamicin	AN2015	B	Swedish (Danish MDC: 0.10 mg/l)	(4)	0.12	3	16	0.12	0.12	0.12
Imipenem	AN2016	A	Algal (Danish MDC: 0.10 mg/l)	(2)	0.12	3	16	0.12	0.12	0.12
Levofloxacin	AN2017	B	Swedish (Danish MDC: 0.10 mg/l)	(4)	0.12	3	16	0.12	0.12	0.12
Meropenem	AN2018	A	Algal (Danish MDC: 0.10 mg/l)	(2)	0.12	3	16	0.12	0.12	0.12
Moxifloxacin	AN2019	B	Swedish (Danish MDC: 0.10 mg/l)	(4)	0.12	3	16	0.12	0.12	0.12
Nicotinamide	AN2020	B	Swedish (Danish MDC: 0.10 mg/l)	(4)	0.12	3	16	0.12	0.12	0.12
Oxazolidinone	AN2021	A	Algal (Danish MDC: 0.10 mg/l)	(2)	0.12	3	16	0.12	0.12	0.12
Paracetamol	AN2022	A	Swedish (Danish MDC: 0.10 mg/l)	(4)	0.12	3	16	0.12	0.12	0.12
Rifampicin	AN2023	B	Swedish (Danish MDC: 0.10 mg/l)	(4)	0.12	3	16	0.12	0.12	0.12
Tetracycline	AN2024	B	Swedish (Danish MDC: 0.10 mg/l)	(4)	0.12	3	16	0.12	0.12	0.12
Vancomycin	AN2025	A	Algal (Danish MDC: 0.10 mg/l)	(2)	0.12	3	16	0.12	0.12	0.12

DK guideline with guiding limit values



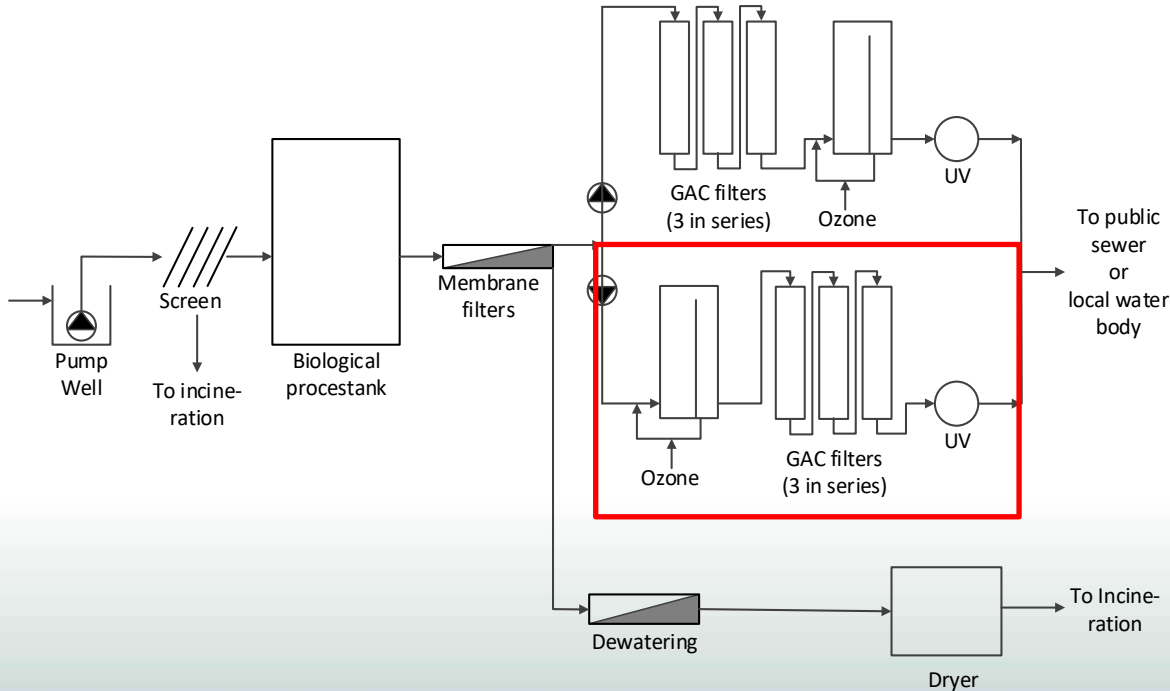
Herlev Hospital WWTP

- **Herlev University Hospital**
 - 850 beds
 - All major clinical specialities (cancer etc.)
 - Water consumption: 170.000 m³/y (200.000 m³/y in 2023)
- **Full scale treatment plant**
 - Constructed in 2013-14. Operated since May 2014
 - Full solution with water, air and sludge treatment
 - Private-Public innovation Partnership (PPP)
- **Catchment Area**
 - Large catchment area in Copenhagen
 - WWTP load 0,4 mio. PE incl. two large hospitals





Treatment process

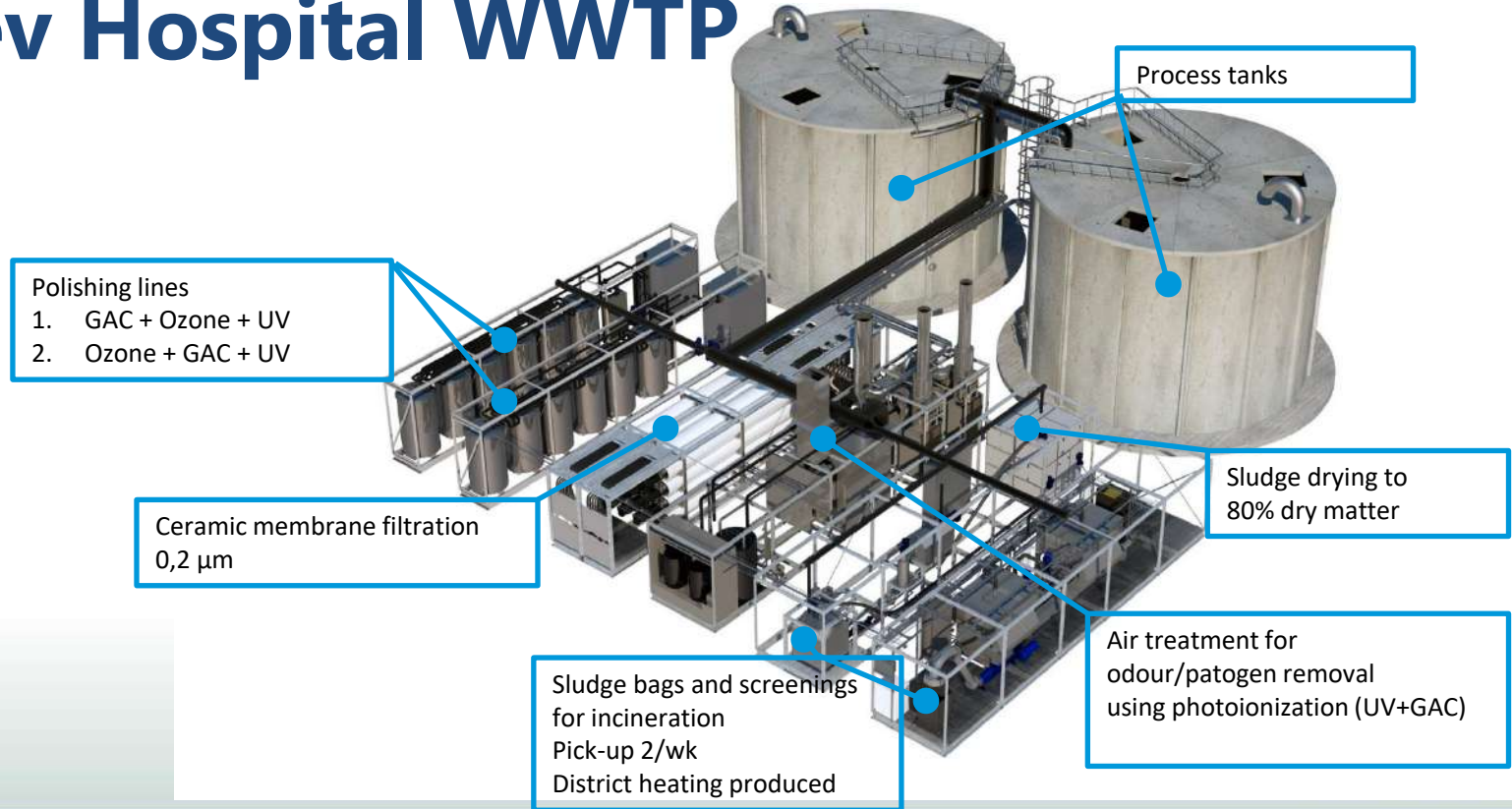


Extensive test program:

- Pharmaceuticals (131)
- Chemicals
- Volatile substances
- Ecotoxicity
- Estrogen activity
- Radioactivity
- Resistant bacteria
- Virus
- Air parameters
- Operational parameters
- GAC parameters
- Sludge parameters



Herlev Hospital WWTP





Treatment efficiency

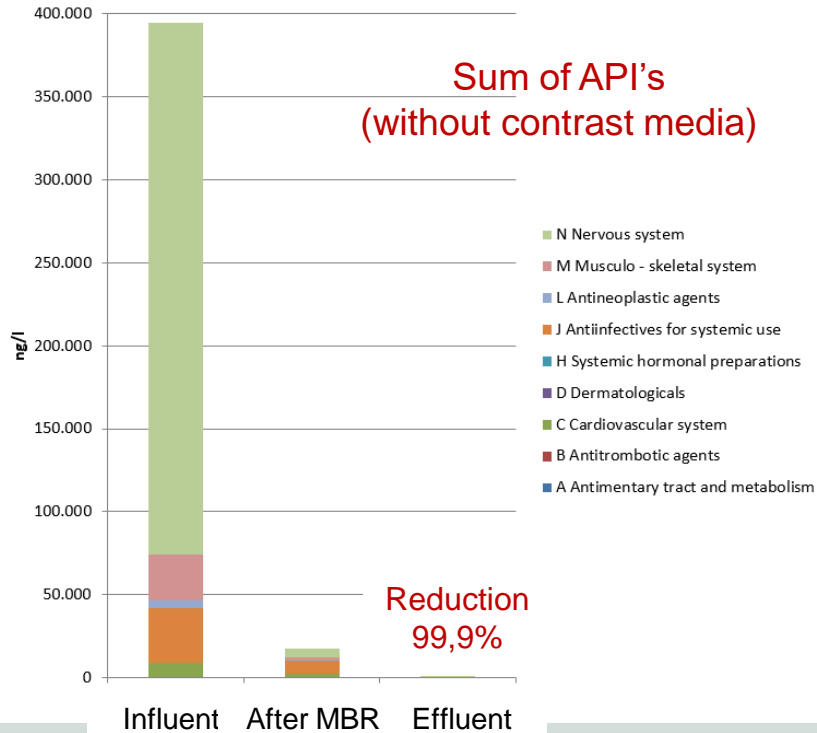
- Analysed: 131 API's incl. metabolites in 118 samples
- Influent: 21 API's above PNEC
- After MBR: 14 API's above PNEC
- Effluent: No API's above PNEC

Influent	After MBR	Effluent
Atorvastatin (0.6 - 6.5)	Azithromycin (2.3 - 8.1)	No pharmaceuticals exceeding PNEC _{Freshwater}
Azithromycin (2.8 - 21)	Carbamazepine (0.7 - 1.3)	
Capecitabine (0.1 - 11)	Cefalexin (LOD - 3.2)	
Carbamazepine (LOD - 2.0)	Ciprofloxacin (4.6 - 93)	
Cefalexin (LOD - 8.4)	Clarithromycin (2.2 - 10)	
Ciprofloxacin (20 - 303)	Diclofenac (4.2 - 11)	
Clarithromycin (1.7 - 130)	Erythromycin (0.3 - 1.1)	
Diclofenac ((3.0 - 11)	lomeprol (LOD - 1.0)	
Erythromycin (0.3 - 26)	N4-Acetyl-Sulfamethoxazole (0.4 - 1.9)	
Ibuprofen (1.5 - 13)	Ofloxacin (LOD - 1.5)	
lomeprol (0.2 - 5)	Sulfamethoxazole (11 - 64)	
Metonidazole (LOD - 2.1)	Tramadol (1.2 - 2.0)	
N4-Acetyl-Sulfamethoxazole (15 - 108)	Venlafaxine (5.2 - 7.7)	
Ofloxacin (LOD - 3.3)	Zopiclone (0.6 - 4.7)	
Paracetamol (6.5 - 87)		
Prednisolon (LOD - 16)		
Sulfamethoxazole (21 - 133)		
Sulfapyridin (0.1 - 3.7)		
Tramadol (LOD - 4.2)		
Venlafaxine (2.5 - 11)		
Zopiclone (LOD - 5.3)		

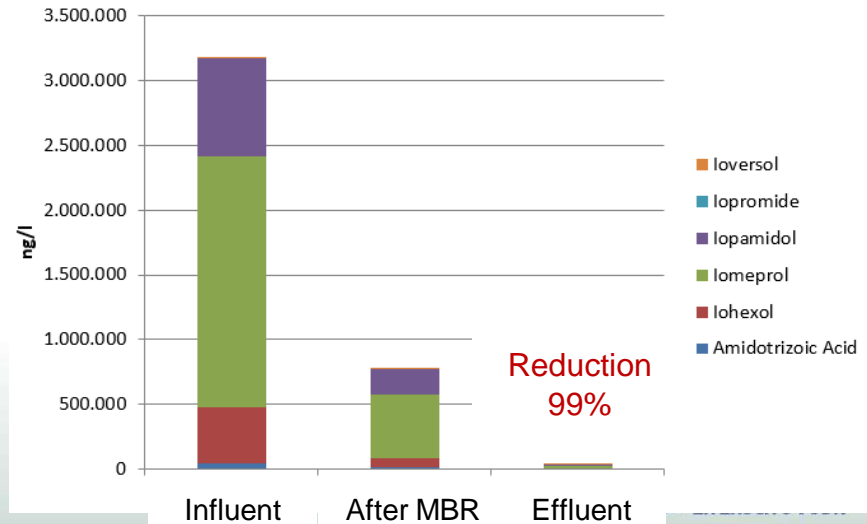


Removal of API's

Sum of API's
(without contrast media)



Sum of contrast media





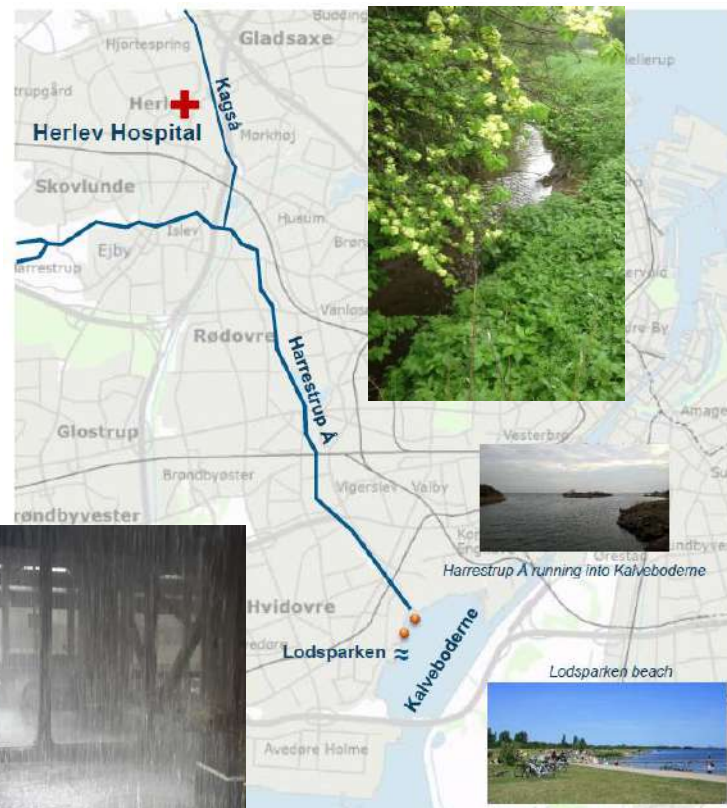
Summary

Parameters	Raw untreated wastewater	Treated wastewater
Toxic and persistent antibiotics (e.g. ciprofloxacin, clarithromycin and sulfamethoxazole), painkillers (diclofenac) and cytostatics (e.g. capecitabine)	Factor 10-300 exceeding of effect limits ($PNEC_{Freshwater}$) for water living organisms	99.9% removal and no exceeding of effect limits ($PNEC_{Freshwater}$) for water living organisms
Contrast media (e.g. iomeprol)	High concentration (2,5-7 mg/l)	99% removal
Antibiotic resistant bacteria	High occurrence of antibiotic resistant bacteria	No fecal or antibiotic resistant bacteria
Water born viruses (norovirus)	High concentration ($1.7 \cdot 10^5$)	Under limit of detection (<26 GC/l)
Fish fry (zebra fish)	100 % mortality within 96 hours	0 % mortality within 96 hours
Crustacean (daphnies)	No offspring (all test animals died)	Offspring survives as in clean control water
Estrogenic activity (A-YES)	Estrogen effects	No estrogen effects



New water resource

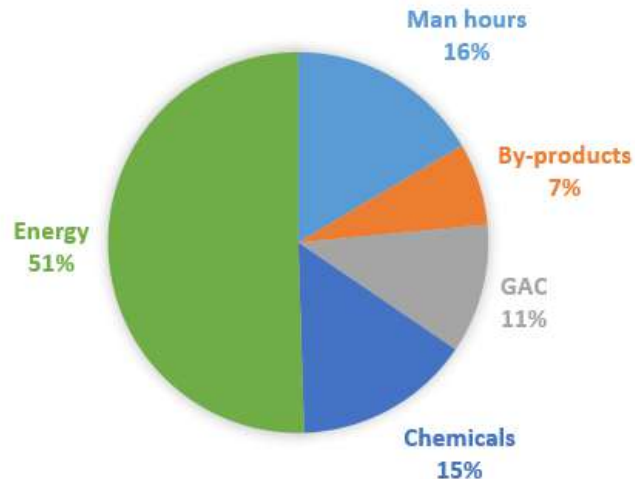
- **Discharge to local stream**
 - Treated wastewater helps to keep the water level during drought season
- **Reuse as cooling water**
 - Around 2,700 kgal/yr from May to September
- **Other potential uses**
 - Irrigation
 - Fountains and ponds





Economy

TOTAL COSTS – 1.45 EUR/M³



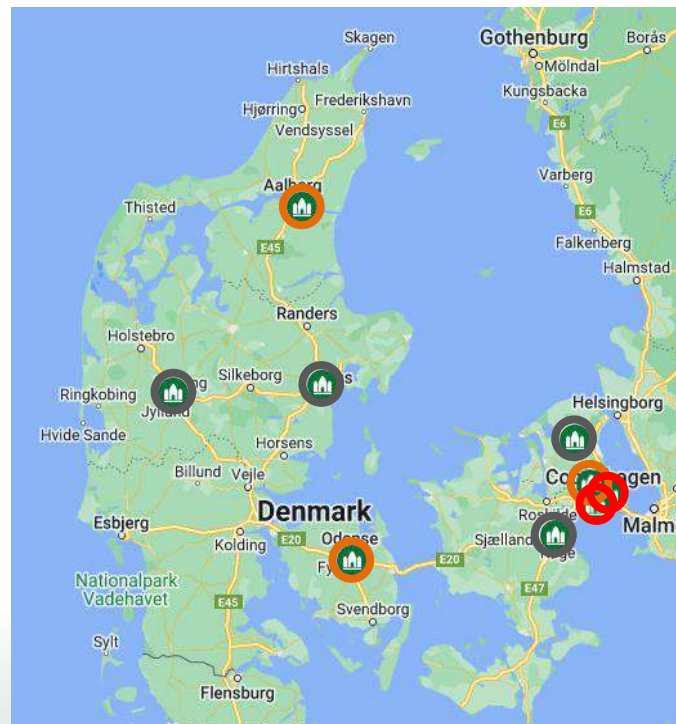
- Total operating and maintenance costs: 1.45 EURO/m³
- Total investment cost: 3.3-4.7 mEUR (new plant)
- Simple pay back period, saving the sewer tax*:
4 mEUR/0.4 mEUR/y = 10 years
- For old hospitals with combined sewer systems the separation of wastewater can exceed the cost of the WWTP

*Sewer tax in Herlev: App. 3,4 EUR/m³



Where are we today?

- Different approaches depending on the catchment area (central vs decentral treatment)
- Orange: Decentral treatment in Hospital WWTP with direct discharge
- Grey: Planning fullscale central treatment in public WWTP
- Red: Awaits decision





Summary

- Public WWTP's are a source of pharmaceuticals to the water areas
- Larger hospitals (>500 beds) are point sources for pharmaceuticals, but households also contributes significant to the load – depending on the specific API
- Though the hospital wastewater is diluted when sent to the public WWTP and therefore more difficult to treat
- Treated hospital wastewater can be seen as a resource instead of a waste product - especially in areas with low water levels



Thank you for your attention